VFD Technology's Energy Conservation Application at Metro Ventilation Air-conditioning System

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Abstract: Shenzhen metro has been applied the VFD control technique and close loop negative control logic to adjust and control the temperature and humidity of public area and conserve the energy on HVAC system of children palace station and Fumin station of N_O.4 line of the first phase project of the metro, which can save over 70% electrical energy than before. And the equipment operated very well in more than one year, and the environment quality is very stable, has achieved obvious efficient.

Key words: Metro, VFD Control Technique, Close Loop Negative Control Logic, Energy Saving, VAV System

1. PROJECT BACKGROUND

The trains of metro and mechanical equipments consume amounts of electrical energy. About 40% directive cost of metro is electricity consumption, but more than 50% costs of them is the air conditioning ventilation system consumption. Therefore, it is very important for the metro station to conserve the energy consumption of HVAC system. Shenzhen metro has been applied the VFD control technique to conserve the energy on HVAC system of children palace station and Fumin station of N_O.4 line of the first phase project of the metro, which can save over 70% electrical energy than before. And the equipment operated very well in more than one year, and the environment quality is very stable, has achieved obvious efficient.

2. SYSTEM COMPOSITION AND CONTROL PRINCIPLE

The HVAC system of the metro station belongs to the comfort HVAC system, and has the high requirement for the indoor temperature control, instead of the low requirement for fluctuation range of the relative humidity. It allows a bigger air supply temperature difference, which is very suitable for applying VAV HVAC system.

There is a big change about the cold and humid load at the metro station within one day. When the cold load reduces, we can make full use of the allowable maximized air supply temperature difference to reduce the air supply volume of supply fan for controlling the indoor temperature. The air supply volume will be changed with the change of the indoor load, and the return air volume will be adjusted relatively for keeping the indoor positive pressure value. When the fan volume reduces, the fan power will be reduced. It will reduce the energy operation consumption of the equipment for achieving energy conservation and operation cost saving.

2.1 System Composition

The public area of the metro station includes the platform and platform hall. Due to the connection between the platform and platform hall, we can take them as one room to adjust and control.

The HVAC system of the public area of the metro composes of AHUs, air-conditioning units and returns and exhaust air units. And arranging one AHU, two air conditioning units and return and exhaust air units at each end of the station.

To furnish VFD for the air conditioning fan and return and exhaust fan, and control the turning speed of fan by VFD through EMCS system to realizing VAV control.

System composition is shown in Fig.1.

The HVAC system of the metro station is very different from the normal one, which has the ventilation and exhaust function, besides air adjustment function.

2.2 Control logic

To automatically adjust and control the temperature and humidity of public area through applying close loop negative control logic. Firstly, based on the environment control requirement, installing 12 sets temperature and humidity probe in the different area of the platform and platform hall of metro, and get average value through the collected data, taking it as the actual measurement temperature and humidity value of the public area of metro. Then to compare the actual value with the setting value, and the automation system will perform in accordance with the comparable result and output the operation result to the VFD for dynamic adjust the opening degree of the electrical valve and the input frequency of the fan electrical machine. Therefore, will achieve the environment temperature and humidity control of the public area of the metro station; the procedure describes below:

When the return air temperature equals to the given value, the mechanical frequency in the air conditioning box of the supply air fan and the exhaust fan frequency will keep the same; when the return air temperature is above the given value, must keep the out taken air supple temperature of the air conditioning box the same like before (no change about the opening degree of the two ducts valve on the cooling and return pipe), Contemporarily, enhancing the frequency of the air supply fan and exhaust fan, increasing the input cold air volume for the public area for reducing the temperature. By the same token, when the return air temperature is below the given value, reduce the frequency of the air supply fan and exhaust fan and the input volume of the cold air for the public area of the metro station, in order for rising the temperature of the public area of the station.

When the return air humidity equals to the given value, no change with the frequency of the air supply fan and exhaust fan and the opening degree of the electrical valve on the cold and return duct, the same with the out taken air supply temperature; when the return air humidity is above the given value, keep the fan operation frequency the same, and increase the opening degree of the electrical valve on the cold and return water pipe and cold water supply volume, as reduce the supply temperature, as reduce the air supply humidity ; By the same token, when the return fan humidity is below the given value, keep the fan operation frequency the same, reducing the opening degree of the electrical valve on the cold and return water pipe and cold water supply volume, as enhance the supply temperature, as enhance the air supply humidity.

2.3 Formula

Air volume

$$G=Q/1.01(t_N - t_O) \text{ and } G=W/(d_N - d_O) \qquad (1)$$

Where G is Air conditioning air supply volume, kg/s; Q is indoor hot load, kW; W is indoor humid load, kW; t_N is dry ball temperature at public area of the platform and platform hall, □; t_O is Air conditioning box air supply dry ball temperature; d_N is humidity

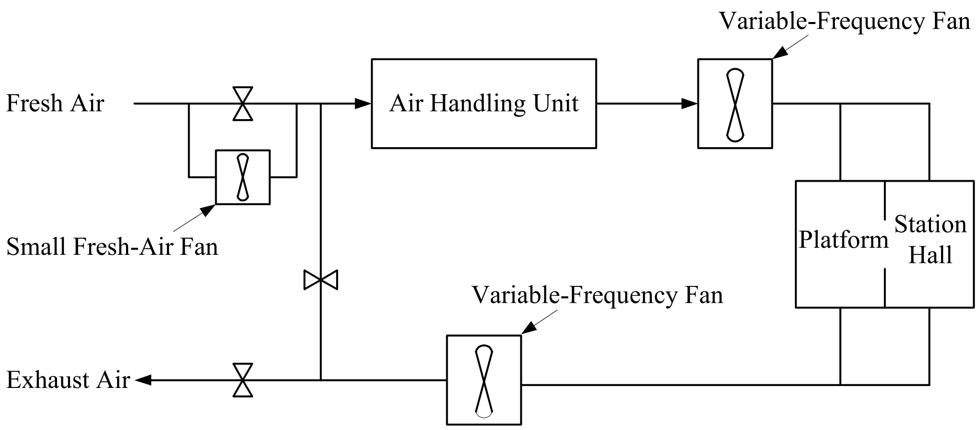

Fig. 1 System composition

volume at public area of the platform and hall, kg/kg; d_O is humidity volume in air conditioning box, kg/kg.

From the formula, in order for adapting the change of load, we can conclude that we adopt to change the air supply volume G and keep the $(t_N - t_O)$ or $(d_N - d_O)$ the same. This is the basic principle for the VAV system.

2.4 Control Flow

There is a big space between the platform and hall for adjusting, and has the up and low level, it is not convenient for cold volume to diffuse, resulting to later adjustment. And have lots of interface factors: the object for adjusting is a big space, and hugely affected by the in and out door of metro station; the human beings flow is another big factor to affect adjustment. Taking the platform and hall as the adjustment object, but platform is a fiducial for adjusting.

The control logic is shown in Fig.2; the control flow is shown in Fig.3.

3. TEST CONDITION & TECHNIQUE PARAMETERS.

The Children palace station's air-conditioning system is consist of 4 air-conditioning boxes, 4 return air fans and 2 fresh air units. They are separated in the two sides of the platform, each side include: 2 air-conditioning boxes, 2 return air fans and a fresh air unit. Since there aren't many passengers, running one set of the equipment on each side is enough. Here is the measured data from September 5~9:

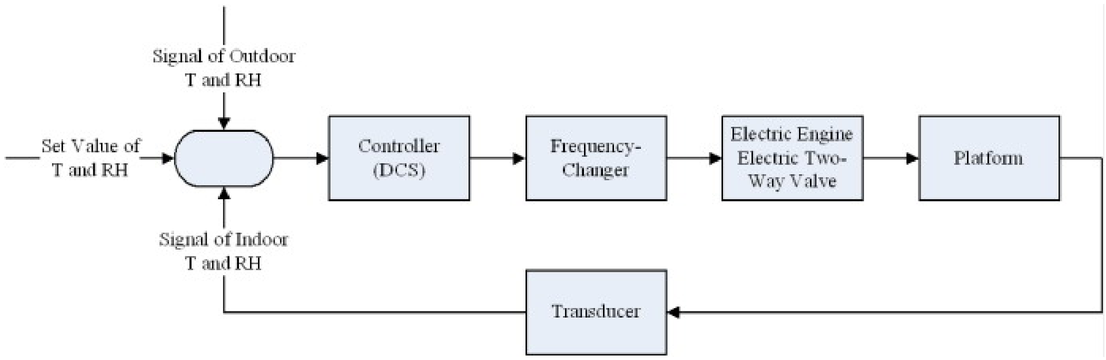

Fig.2 The control logic diagrame

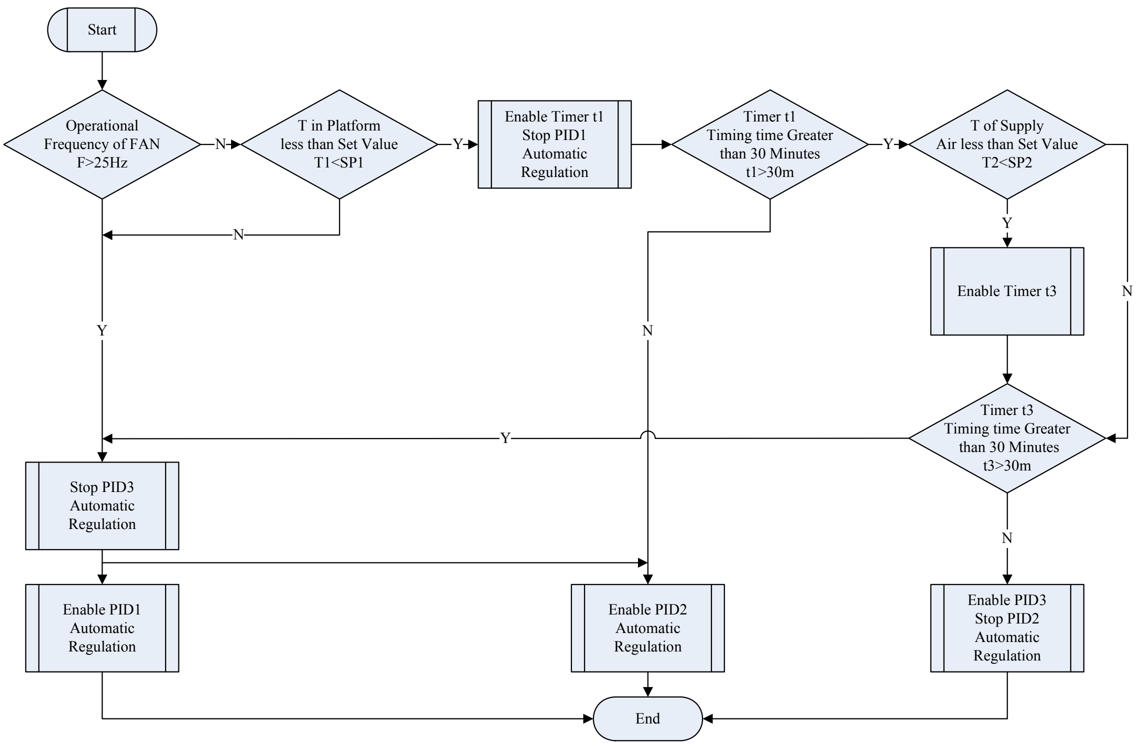

Fig.3 The control flowchart

1. Designed airflow of air-conditioning boxes: 50000(m^3/h); designed power: 30(kW)

2. Designed airflow of return air fans: 30600(m^3/h); designed power: 11(kW)

3. Designed airflow of fresh air units: 13320(m3/h); designed power: 1.1(kW)

4. Dimension of public area: 3260 m^2 Total volume: 3260×3.0= 9780 m^3

5. Temperature in Hall: 29℃ humidity: 60%~65%

6. Temperature in platform: 26℃ humidity: 60%~65%

7. KT-1, KT-4and HPF-1, HPF-4 working at VF condition.

8. XXF-1, XXF-2 working at rated condition.

9. Chilling water's temperature: 7℃, 12℃

10. Outdoor temperature: 33℃.

HVAC control diagram is shown in Fig.4.

Cold water system control diagram is shown in Fig.5.

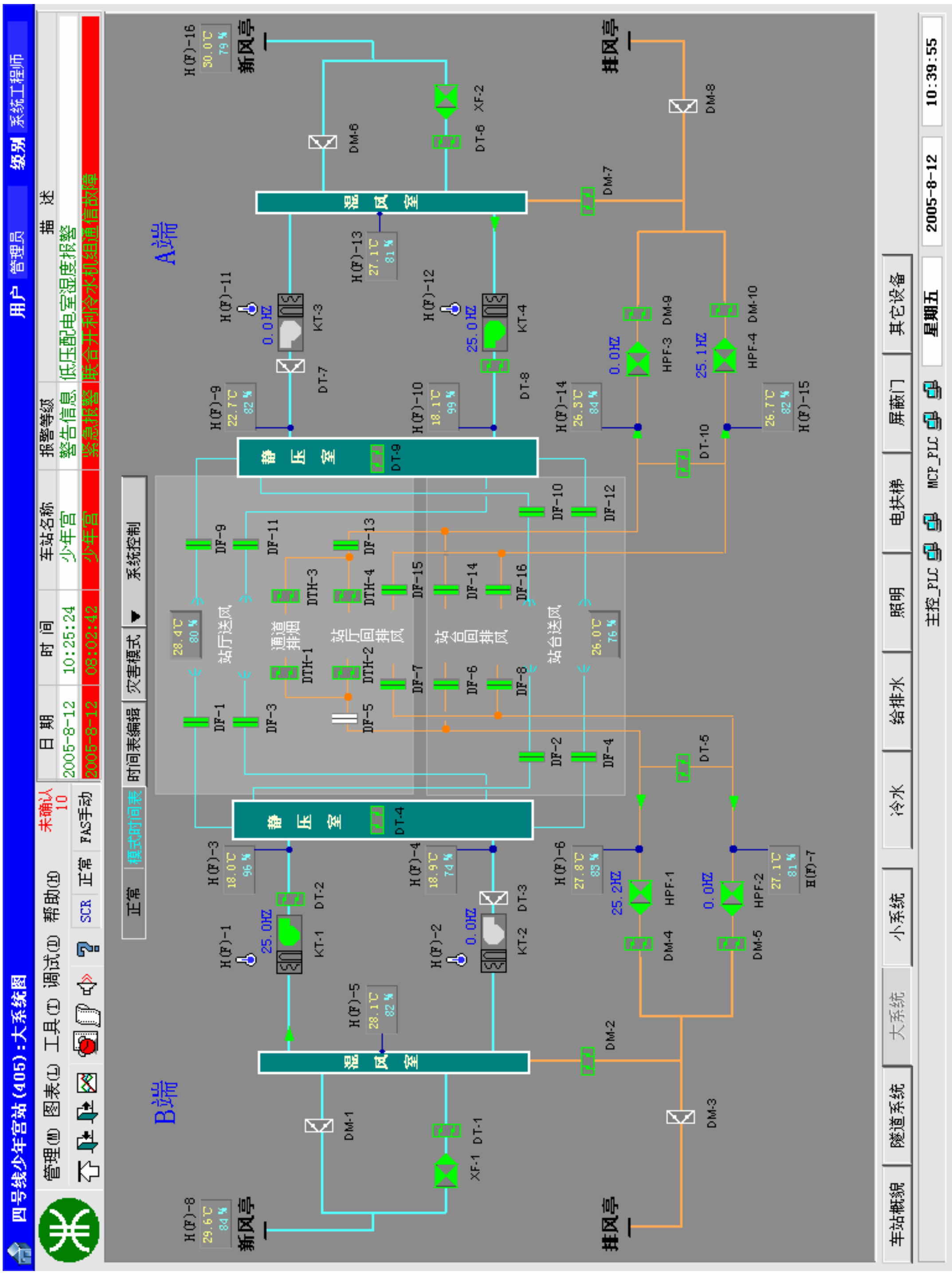

Fig.4 HVAC control diagram

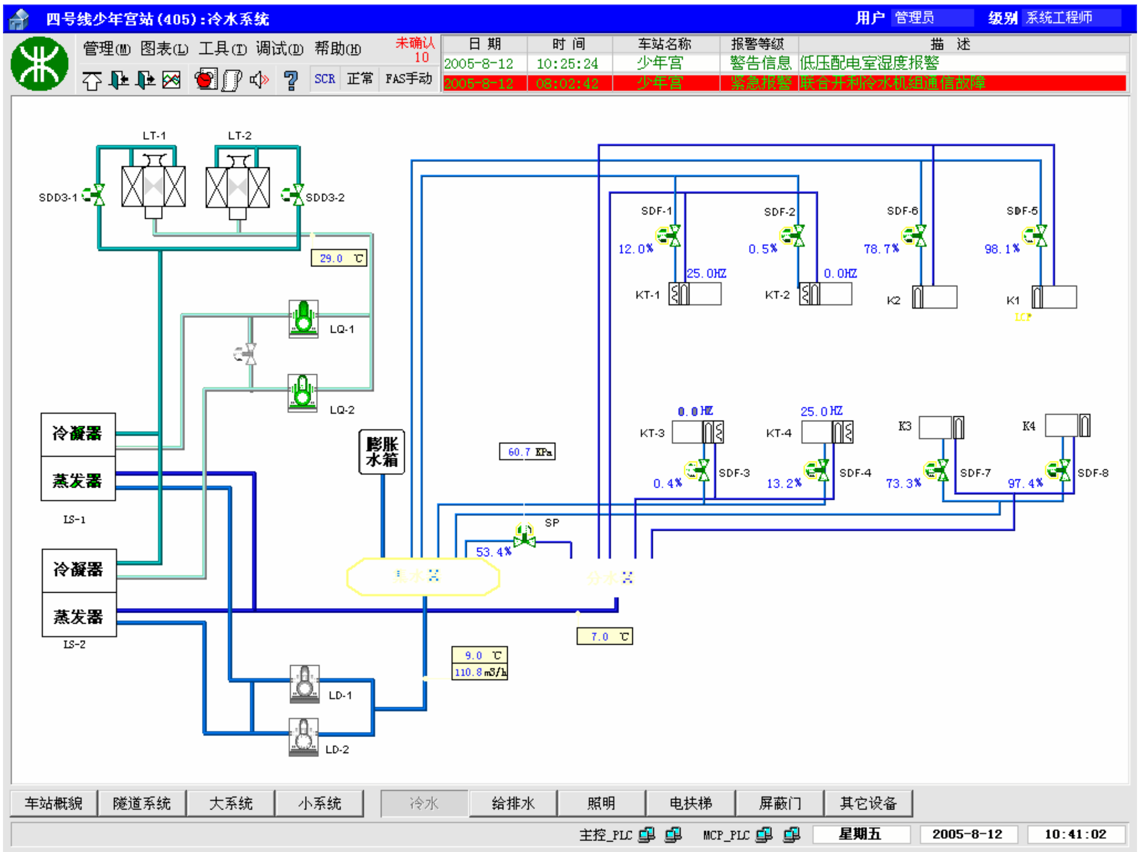

Fig.5 Cold water system control diagram

4. TEST METHODS & STEPS

1. Recording the supply fans' frequency and return fans' frequency by using EMCS.

2 Installing the current instrument transformer and kilowatt at the main power supply loop of the air conditioning box and exhaust fan cupboard, and measure the input power of the air conditioning box and exhaust fan;

3. From 6: 00am to 11: 30 pm, record the supply fans' frequency and return fans' frequency every 8 minutes.

4. Recorded the energy consumption of air-conditioning boxes & return air fans every night.

5, Label the kilowatt under the valid date.

5. CALCULATIONS AND METHODS. C

According to resemblance principle, use the relationship between airflow, air pressure, power, speed and frequency of fans at different frequency; we calculate basing on the following formula[1]:

$L/L_0=n/n_0$ $N/N_0=(n/n_0)^3$

$n/n_0=f/f_0$ $P/P_0=(n/n_0)^2$

In the formula, L, P, N is the measuring equipments of airflow, pressure, power when the pump's speed is n.

1. Airflow:

According to: $L/L_0=n/n_0$ $n/n_0=f/f_0$

$L/L_0=f/f_0$

We got: $L=f \cdot L_0/f_0$

PS: f_0 is the frequency under rated condition; 50Hz. f is the actual frequency at a certain moment. L_0 is the designed airflow. We can calculate the actual airflow of a certain time by measuring the fans' actual frequency.

2. Calculate the power through fans' frequency:

According to: $N/N_0=(n/n_0)^3$

$n/n_0=f/f_0$

$N/N_0=(f/f_0)^3$

We got: $N=N_0 \cdot (f/f_0)^3$

PS: f_0 is the frequency under rated condition, 50Hz. f is the actual frequency at a certain moment, N0 is the input power, the fans' actual power calculated by airflow & pressure: $N_0=(L_0 \cdot P_0)/\eta_1 \cdot \eta_2$

In the formula: L_0 is rated airflow, P_0 is the rated pressure, η_1 is the efficiency at full pressure situation, η_2 is the motor efficiency. N_0 is the fans actual power; we can calculate the actual input power by measuring the actual frequency.:

$N = N_0 \bullet (f/f_0)^3 = (f/f_0)^3 \bullet (L_0 \bullet P_0)/\eta_1 \bullet \eta_2$

3. Energy consumption:

Formula: $P = \sum N_i \bullet t_i$

PS: N_i, t_i is the fans' input power and time gap, since the fans' input power changes as the time changed, so we can make some simplification from the view of engineering. That's: at a time gap that is short enough, the fans' input power is constant, so we can take it as a constant value if the time gap is short enough, without affecting the accuracy. After we have find out the energy consumption of every small time gap, we can add up the energy consumption of all day's time gap, which equals the whole day's energy consumption. Now we start the system from 6: 00 am to 11: 30 pm and record the supply fans' frequency and return fans' frequency every 6 minutes. After that we will follow the calculation steps above.

6. CALCULATED DATA, FREQUENCY AND TEMPERATURE CURVE

The calculated data is shown in Tab.1~Tab.4.

The frequency and temperature curve is shown in Fig.6.

7. CONCLUSION

1. The air-conditioning system of Shao Nian Gong station' public area is designed to install 4 air-conditioning boxes and 4 return air fans. When outside temperature is 33℃, we can fulfill the designed index with 2 air-conditioning boxes and 2 return air fans online. The index include: 29℃ in station hall, humidity 55%~75%; platform temperature 26℃, humidity 55%~75%; fresh air 38 % (the minimum of the fresh air is 10%); 5 circulations per hour. The air-conditioning boxes will save 84% energy on average under vary frequency model and the fans will save 83%. Taking errors into account, the average energy saving should be 70%.

Tab.1 The Actual measurement frequency record and related data on 2005-9-5

TIME	KT-1 Frequ-ency	KT-1 Air Volume	KT-1 Elec-tricity	KT-4 Frequ-ency	KT-4 Air Volume	KT-4 Elec-tricity	HPF-1,4 Frequ-ency	HPF-1,4 Return Air Volume	HPF-1,4 Electricity	Platform/ Hall temperature	New air rate	Air Exc-hange
6:08:00	19.5	2602.0	0.2	25.7	1594.0	0.4	20.0	1920.0	0.2	26.5/27.4	0.38	3.3
06:16:00	49.2	6555.0	2.8	49.2	6555.0	2.9	49.7	4053.0	1.3	26.0/26.7	0.38	10
06:24:00	45.3	6039.0	2.2	45.4	6039.0	2.2	45.9	3747.0	1.0	25.4/26.5	0.38	9.2
06:32:00	38.8	5175.0	1.4	38.9	5175.0	1.4	39.3	3200.0	0.6	25.1/26.6	0.38	7.9
06:40:00	30.8	4110.0	0.7	30.9	4110.0	0.7	31.1	2533.0	0.3	25.0/26.7	0.38	6.3
06:48:00	25.5	3393.0	0.4	25.5	3393.0	0.4	25.6	2093.0	0.2	25.2/26.9	0.38	5.2
06:56:00	25.0	3333.0	0.4	25.0	3333.0	0.4	25.2	2053.0	0.2	25.2/27.1	0.38	5.1
7.04~23.22	25.0	410000	49.2	25.0	410000	49.2	25.2	252560.0	24.6	26.0/29.0	0.38	5.1
23:28:00	25.0	3333.0	0.4	25.0	3333.0	0.4	25.2	2053.0	0.2	25.7/28.0	0.38	5.1
Totaling for VFD Volume		444540	57.7		443532	58.0		2×272572	2×28.6		0.38	5.0
Stable Frequency Volume total			425			425			2×172			
Energy Saving %			86.3 %			86.3 %			83.2%			

Tab.2 Children Palace Air Conditioning Box Frequency, Fan Volume, Axis Power Measurement Record Statistic Table

Frequency (H_Z)	Fan Volume (m3/h)	Fan Volume Rate	Whole Pressure (pa)	Pressure Rate	Axis Power (KW)	Power Rate	Energy Saving Rate
50	49645	100%	519	100%	17.6	100%	0%
45	43110	86%	420	80%	12.8	72%	30%
40	39301	78%	331	60%	9.0	51%	50%
35	34208	68%	259	50%	6.0	34%	75%
30	28977	58%	182	35%	3.8	21%	80%
25	24109	48%	126	24%	2.2	13%	87%

Tab.3 Air Conditioning Box and Air Supply Fan VFD Energy Consumption Statistic Table

	KT-1	KT-4	HPF-1	HPF-4
2005-9-5	54.9	55.3	24.9	24.7
2005-9-6	62.8	63.3	28.5	28.4
2005-9-7	65.8	66.3	29.8	29.7
2005-9-8	64.0	65.1	29.0	29.1
2005-9-9	64.1	65.2	29.1	29.2
Totaling for VFD Volume	62.3	63.0	28.3	28.2
Stable Frequency Volume total	425.0	425.0	172.0	172.0
Energy Saving %	(425-62.3)/425=85%	85%	83.5%	83.5%

Tab.4 Average Air Supply and Return Volume Statistic Table

	KT-1 (m^3/s)	KT-4 (m^3/s)	HPF-1 (m^3/s)	HPF-4 (m^3/s)	New Air Rate	Air Exchange Times
2005-9-5	441938.0	441938.0	272292.0	270652.0	0.38	5.0
2005-9-6	424145.0	424145.0	262368.0	262368.0	0.38	5.0
2005-9-7	448306.0	448306.0	284310.0	284310.0	0.38	5.0
2005-9-8	462524.0	462524.0	284531.0	284531.0	0.38	5.0
2005-9-9	457652.0	457652.0	281520.0	281520.0	0.38	5.0
Average Air Volume	446913.0	446913.0	277004.0	276676.0	0.38	5.0

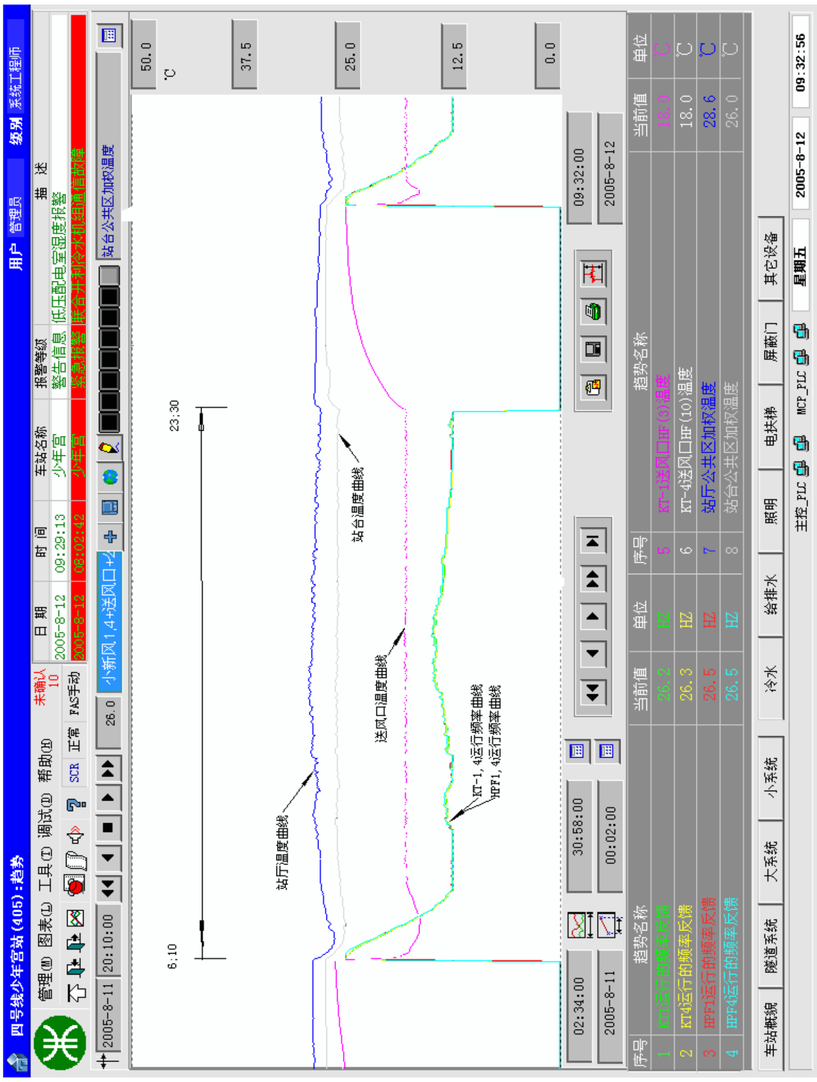

Fig.6 The frequency and temperature curve

2. Since the Shao Nian Gong station belongs to Line 4, which doesn't have many passengers, the burden of the air-conditioning system can't be heavy. Considering there will be more passengers in the future, the other 2 air-conditioning boxes & fans can be put to use to maintain the stations' condition. Suppose the average energy saving of the public area is 84%, we can calculate that the maximum passengers of the public area per day is: 2×441938(m^3/day)×1.2(kg/m^3)×3(kcal/kg)×1.163 (w/kcal) /150(W/person)=24670(person/day).

3. The calculation above indicates that the Shao Nian Gong station can afford is about 25 thousand passengers per day. Taking other 19 stations into account, the total passengers per day should be 500 thousand. Such number can maintain our recent objects.

4. If working under rated condition, every air-conditioning box have an airflow of 50000(m^3/h)×17.5 (h) = 875000(m^3) per day.

Under VF condition, the fans will only working at a high frequency at the beginning, the rest of the time it is generally working at constant frequency of 25Hz. So, according to the fan's mechanical peculiarity, the boxes' total airflow under VF condition should be 50% of that under rated condition. The Shao Nian Gong station's measured airflow of September 5th ~9th is 446913(m^3), and compare to the rated condition is: 446913(m^3)/875000(m^3) =51%; just as we have calculated.

5. As the caculation above, the total airflow of return air fan per day is: 30600 (m^3/h)×17.5(h) =535500(m^3)

Under VF condition, the fans will only working at a high frequency at the beginning, the rest of the time it is generally working at constant frequency of 25Hz. So, according to the fan's mechanical peculiarity, the boxes' total airflow under VF condition should be 50% of that under rated condition. The Shao Nian Gong station's measured airflow of September 5th ~9th is 277004(m^3), and compare to the rated condition is: 276676(m^3)/ 535500 (m^3) =51.7%, just as we have calculated.

6. The designed total burden of Shao Nian Gong station is
4×50000(m^3/h)×17.5(h)1.2(kg/m^3)×3(kcal/kg)×1.163 (w/kcal)/(1.2×1000)=12211.5(kW),
and the measured burden of September 5th~9th is 2×446913(m^3)×1.2(kg/m^3)×3(Kcal/kg)×1.163(w/kcal)/(1.2×1000)=3118(kW).
The rate of actual value to the designed value is 3118/12211.5=25%.

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